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PERFORMANCE AND ANALYSIS OF THERMAL ENERGY STORAGE SYSTEM USING PCM

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ABSTRACT

Thermal energy storage systems are currently undergoing a revolution, vowing to their influential involvement in modern technology, and their extensive applications such as space heating, water heating, waste heat utilization, cooling and air conditioning. Energy storage is substantial, whenever there is a gap between the supply and consumption of energy. Multiplying energy demands, lack of fossil fuels and the continuing boom in the level of greenhouse gas emissions are the predominant driving forces to focus on various sources of renewable energy. Solar thermal energy storage devices need heavier research attention due to irregular and unpredictable nature of solar energy which is quite efficient, economical and reliable energy resource. Among the various types of possibilities to store energy systems using different materials, Phase Change Materials (PCM) can be preferred for their consistency in latent heat storage. The usage of PCM is an effective way of storing thermal energy and has the advantages of having high storage density and is isothermal in nature of the storage process.

In the present experimental work, thermal energy storage system (TESS) is designed, fabricated and commissioned to collect thermal performance data on the thermal energy storage tank. This TES tank is having spherical capsules, embedded with phase change material as paraffin wax and stearic acid. The heat transfer fluid(HTF) is used as water. The present work aims to investigate the charging (melting of PCM) and discharging (solidification of PCM) characteristics of phase change material in TES tank.

KEYWORDS: Thermal Energy Storage System (TESS), Phase Change Material (PCM), Paraffin wax, Stearic Acid, Heat Transfer Fluid (HTF), Charging & Discharging

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Original Article

INTRODUCTION

The thermal performance and phase change stability of stearic acid as a latent heat energy storage material has been studied experimentally. In this paper, parameters such as transition time, temperature range and propagation of the solid–liquid interface as well as the effect of the heat flow rate on the phase change stability of stearic acid as a phase change material (PCM) were studied [1]. Investigations are carried out in the TES system for different phase change materials (paraffin and Stearic acid) by varying HTF flow rates and for various sizes of spherical capsules [2]. This paper analysed the experimental evaluation of thermal performance of a packed bed latent heat TES unit integrated with solar flat plate collector[3]. The review of this paper has carried out various methods of heat transfer techniques to improve the thermal energy storage system. The paper mainly focused on PCM based thermal energy storage system, which is more adaptable and useful to the energy conservative system

and wrapped current research papers in a particular field [4]. The objective of this study was to experimentally establish thermal energy storage (TES) performance using a technical grade paraffin wax as a phase change material (PCM) in a vertical concentric pipe-in-pipe latent heat storage system. The melting and solidification temperature range of the paraffin was found as 38^{o}C to 43^{o}C and 36^{o}C to 42^{o}C respectively [5]. A shell and spiral type heat exchanger has been designed and fabricated for low temperature industrial waste heat recovery using phase change material. Paraffin wax (Melting Point 54^{o}C) was used as storage media due to its low cost and large-scale availability in Indian market. Experiments were performed for different mass flow rates and inlet temperature of heat transfer fluid for recovery and use of waste heat. The effect of mass flow rate on the performance of the system was studied. Calculations for overall heat transfer during charging (melting of PCM) and discharging (solidification of PCM) and heat discharging efficiency were also made [6]. The aim of this paper is a double pipe type heat exchanger and has been designed and fabricated for low temperature industrial waste heat recovery using phase change material (PCM) paraffin wax (PW) and Latent heat storage (LHS) system with PCM can be successfully used for recovery and reuse of waste heat [7]. The amount of convection and temperature change brought about due to the heat flux has been simulated and studied in detail using GAMBIT and FLUENT and Successful analysis of the transient heat transfer characteristics of phase change material has been studied[8]. An Experimental study of phase change heat energy storage system (PCHES) using Erythritol as a phase change material (PCM) has been carried out[9]. The aim of the study is to improve the understanding of latent and sensible thermal energy storage within a paraffin wax media by an array of cylindrical tubes arranged both in in-line and staggered layouts. An analytical and experimental study is carried out in a horizontal shell-and-tube type system during melting process [10]. An energy storage system has been designed to study the heat transfer characteristics of paraffin wax during melting and solidification processes in a vertical annulus energy storage system [11]. In the present experiment thermal conductivity of wax based storage system is improved by embedding Copper, Aluminium and iron springs. Experiments show that such systems show superior performance during charging and discharging compared simple system with wax as PCM [12]. Eutectic phase change materials (PCMs) that have thermal characteristics appropriate for latent heat thermal energy storage (LHTES) applications have been identified [13]. Thermal energy storage tank is integrated with an IC engine setup to extract heat from the exhaust gas using two types of phase change materials (Paraffin wax type-2 and Stearic acid)[14]. The use of phase change materials (PCMs) in building applications can not only improve the indoor thermal comfort, but also enhance the energy efficiency [15]. Thermal energy storage with phase change materials (PCMs) offers a high thermal storage density with a moderate temperature variation, and has attracted growing attention due to its important role in achieving energy conservation in buildings with thermal comfort. This paper deals with literature review on the thermal energy storage unit to select for best suitable PCM's and materials for the design of the test bench of thermal energy storage unit [16]. Theoretical thermal and fluid flow characteristics of thermal energy storage system using phase change material have been analyzed [17]. Theoretical and experimental performance enhancement technics were analysed in this paper[18]. It is observed that the discharging of the thermal energy storage system was faster with increasing fluid flow rate or decreasing inlet fluid temperature and the variation of the flow rate was effective in charging the discharging time[19]. PCMs have been widely used in latent heat thermal energy storage systems for heat pumps, solar engineering, and spacecraft thermal control applications[20]. This paper describes a short term thermal energy storage unit based on an enclosed PCM in polyethylene film bag.[21]. The present work aims at designing, fabricating on experimental setup that incorporates Paraffin wax and stearic acid(PCM) filled spherical capsules. Experiments are carried out on TESS.

EXPERIMENTAL WORK

Thermal energy storage system consists of TES tank, water storage tank, PCM capsules, flow control valve, flow meter and digital thermometer. Water is filled in water storage tank after that water is heated approximately up to 70^0C with constant heat source slowly. Later on the hot water is allowed to flow into the thermal energy storage tank with the help of flow control valve and flow meter. TES tank consists of spherical capsules containing PCM such as stearic acid and paraffin wax. Phase change material absorbs heat slowly up to melting point. This is known as charging process. In this way experiments were conducted for mass flow rates of 2 lit/min, 4 lit/min and 6 lit/min. Schematic diagram of thermal energy storage system is represented in figure 1and figure 2 indicates spherical capsules having diameter of 60 mm and made by mild steel material. Specifications of cylindrical TES tank represented in Table1and Properties of PCM mentioned in Table2.

Figure 1: Schematic Diagram of TESS System

Figure 2: Spherical Capsule

Table 1: Specifications of Cylindrical TES Tank

S. No.	Specifications	Units
1	Length	64 cm
2	Diameter	36.5 cm
3	Capacity	50 litrs

Table 2: Properties of PCM

S. No.	Name of PCM	Melting Point (^oC)	Latent heat (kJ/kg)
1	Stearicacid (Commercial grade)	57-59	199
2	Paraffin wax (type-II)	59-62	213

RESULTS AND DISCUSSIONS

Charging Process

During charging process, the hot HTF is circulated through the tank by the pump used in the circuit. The PCM inside the capsules absorbs the latent heat and melts. The difference between the mean temperature of HTF and PCM must be sufficient to obtain a satisfactory rate of heat transfer.

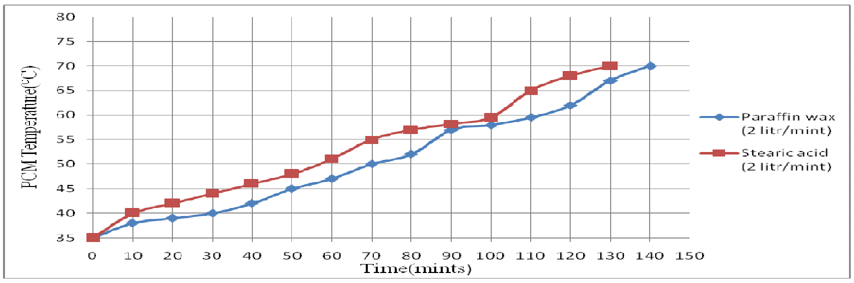

Figure 3: Variation of PCM Charging Temperature with Time and Mass Flow Rate is 2 Lit/Min

From figure 3, it may be observed that PCM temperature increases rapidly till the phase change temperature is reached and remain constant during phase change and later the temperature of the liquid PCM raises gradually and attains heat transfer fluid temperature(HTF). It is observed that when PCM is used as stearic acid, the charging time is 130 minutes and PCM is used as paraffin wax, the charging time is 140 minutes

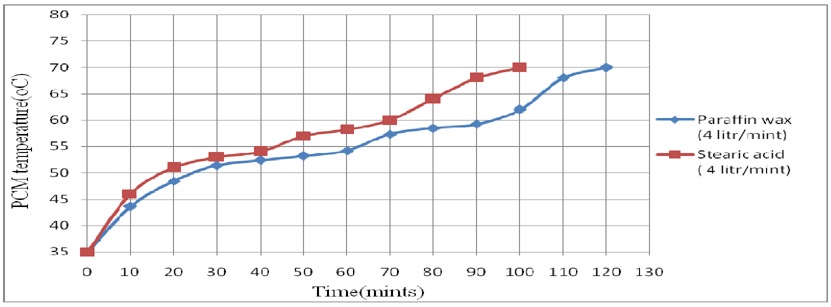

Figure 4: Variation of PCM Charging Temperature with Time and Flow Rate is 4 Lit/Min

From figure 4, it may be observed that PCM temperature increases rapidly till the phase change temperature is reached and remain constant during phase change and later the temperature of the liquid PCM raises gradually and attains heat transfer fluid temperature (HTF). It is observed that when PCM is used as stearic acid, the charging time is 100 mins and PCM is used as paraffin wax, the charging time is 120 mins.

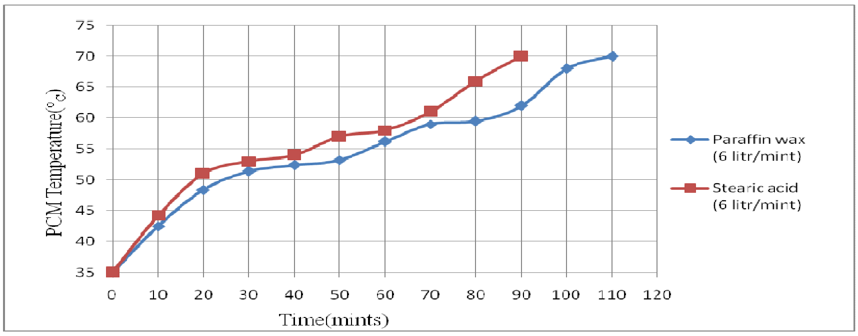

Figure 5: Variation of PCM Charging Temperature with Time and Flow Rate Is 6 Litr/Min

From figure 5, it may be observed that PCM temperature increases rapidly till the phase change temperature is reached and remain constant during phase change and later the temperature of the liquid PCM raises gradually and attains heat transfer fluid temperature (HTF). It is observed that when PCM is used as stearic acid, the charging time is 90 mins and PCM is used as paraffin wax, the charging time is 110 mins.

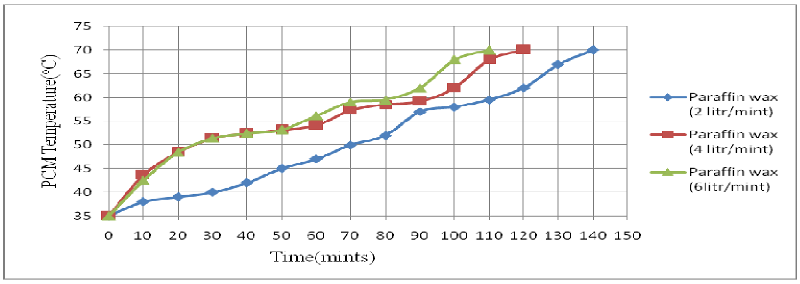

Figure 6: Variation of PCM (Paraffin Wax) ChargingTemperature with Flow Rate is 2 Lit/Min, 4 Lit/Min and 6 Lit/Min

Figure 6 represents the relation between charging time and the PCM temperature for mass flow rates of 2lit/min, 4 lit/min and 6 lit/min of HTF when circulated from a constant heat source, with paraffin wax is used as PCM. For mass flow rate 2 lit/min, the charging time is 140 mins. For mass flow rate 4 lit/min, the charging time is 120 mins. For mass flow rate 6 lit/min, the charging time is 110 mins.

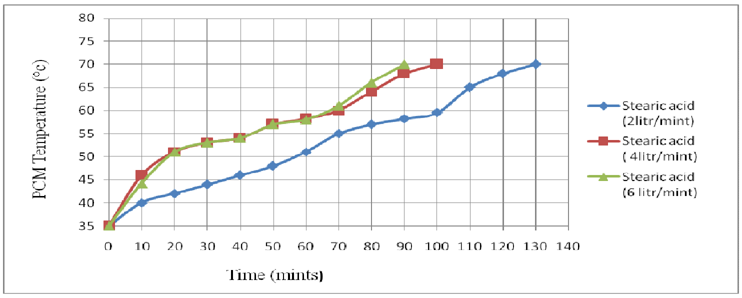

Figure 7: Variation of PCM (Stearic Acid) Charging Temperature with Flow Rate is 2 Lit/Min, 4 Lit/Min and 6 Lit/Min

Figure 7 represents the relation between charging time and the PCM temperature for mass flow rates of 2lit/min, 4 lit/min and 6 lit/min of HTF when circulated from a constant heat source, with stearic acid is used as PCM. For mass flow rate 2 lit/min, the charging time is 130 mins. For mass flow rate 4 lit/min, the charging time is 100 mint. For mass flow rate 6 lit/min, the charging time is 90 mins.

Discharging Process

Discharging is carried out by batch wise process after complete charging of the TES tank. In this process cold water at 2 lit/min at room temperature is let into the TES tank and at the same rate an amount of 30 lit of hot water is with drawn. The temperature of the withdrawn water is noted. The TES tank is again filled with cold water of quantity equal to the amount of water withdrawn. This fixed quantity of 30 lit of water which is withdrawn from the TES tank to facilitate filling up of fresh cold water is termed as batch. After a time interval of 20 minutes allowing for transfer of energy from PCM, another batch of 30 lit of water is withdrawn from the TES tank. This process is continued until the average temperature of the complete amount of water withdrwan is about 35°C. During the discharging process, the temperature of HTF and PCM at various levels of the tank are noted at fixed intervals of time.

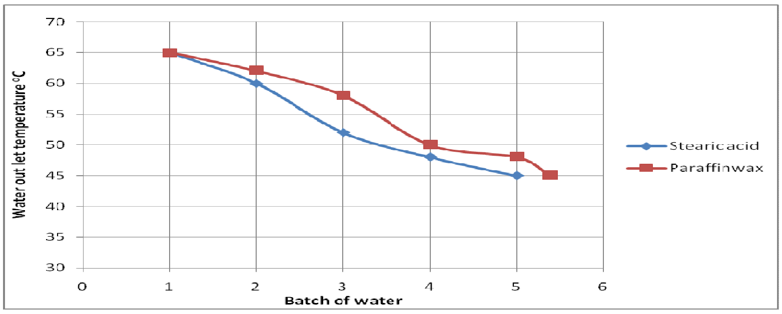

Figure 8: Outlet Water Temperature Vs Batches of Water for Stearic Acid and Paraffin Wax

From the figure 8, it may be noted that 150 litres of hot water is collected when stearic acid is used as PCM and 160 litres of hot water is collected when paraffin wax is used as PCM.

CONCLUSIONS

- It can be observed that the rate of rise of PCM temperature is high initially at all mass flow rates due to high temperature difference between HTF and PCM.
- It is observed that the charging time decreases with the increase in mass flow rate from 2 to 6 lit/min. This is because as the mass flow rate is increased, the thermal energy supplied to the TES tank through HTF in a given time increases. This is causing reduction in charging time with increased mass flow.

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